Astrolabes and Zījes as Tools of Education and the Transmission of Scientific Knowledge from Islamic Civilization

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A while back, as part of a project to trace astrological concepts in medicine through Greek, Arabic and Latin, I was intrigued by what David King and Charles Burnett have written about the role of the astrolabe in transmitting science to the West. George Saliba had taught me in graduate school at Columbia that the zījes played a large role in the development of Islamic astronomy and its transmission. My own fascination with calculating devices and tables is one thing that enticed me into the history of Islamic science in the first place. Together these ingenious tools served scientific education and research in the Muslim world and its intellectual heir, the West, as they had done in the Greek, Persian, and Indian worlds before them.

Although today we know much more about Islamic zījes and astronomical instruments through the research of David King and his students, as he has pointed out there is a mass of material still to be explored—a situation that mirrors the state of the study of Arabic scientific manuscripts generally.

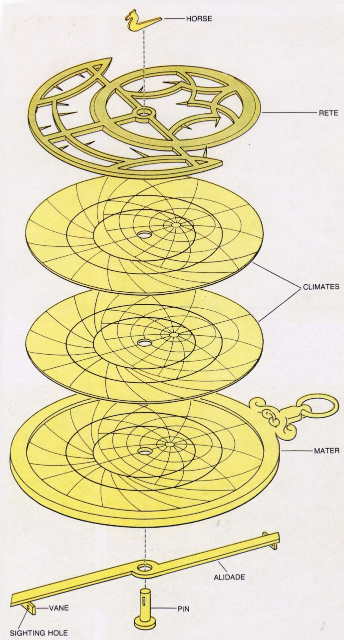
While we can trace the history of astrolabes in terms of treatises on how to construct and use them, and how to use zījes to generate almanacs and ephemerides, there seems to be little or no evidence from actual classroom contexts about how students actually learned these skills.[1]

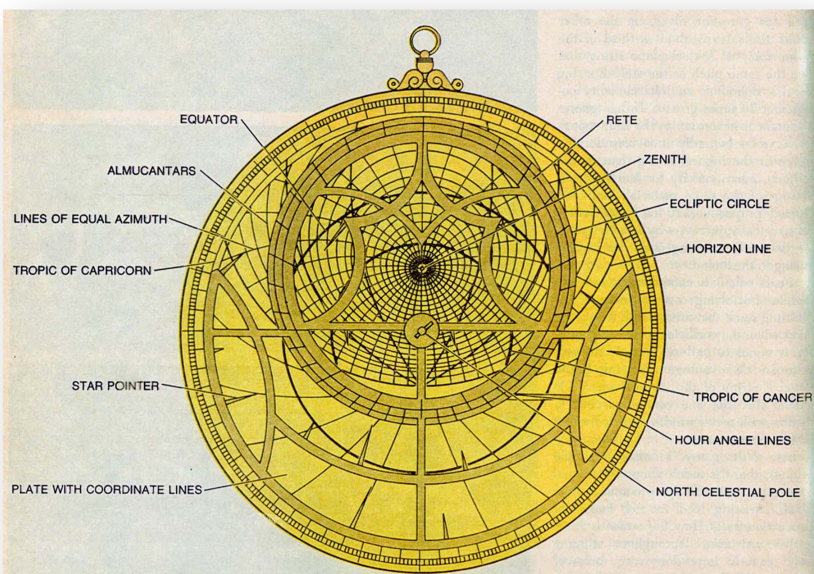
So, in order to get greater insight into the educational context, this semester at Claremont McKenna College I have integrated them into my history of Islamic science course ("Science, from Islam to the West"). Students assemble and learn to use astrolabes, and to perform general astronomical calculations, as well as specifically Islamic ones. And they learn the theory behind planetary tables and use them to calculate the planetary positions to place on their own natal charts. While I don't teach them how to interpret their charts, they gain a hands-on appreciation for the labors of pre-modern astronomers, much of whose livelihoods depended on such astrological applications.

In the present setting, I shall sketch these devices and their histories. Then I shall describe how these devices can be taught in a modern educational context. The historical

[1] The classic study of the history of the astrolabe is: Neugebauer, O. "The Early History of the Astrolabe." *Isis* 40, no. 3 (1949): 240-56.

part of this presentation is based on the works of Professors E. S. Kennedy and D. A. King. The modern part is original with me.





A most ingenious device that is as useful as it is beautiful, Muslim civilization first encountered the astrolabe in Harran, where there were astrolabe workshops,

according to one view.[2] Harran was a site of continued Hellenism in Late Antiquity. Muḥammad ibn Ibrāhīm al-Fazarī (8th C.) reportedly was the first Muslim to construct one, but the oldest extant Islamic astrolabe dates from late 8th C. Baghdad, and is a copy of a Byzantine exemplar.[3] The earliest surviving Arabic treatise on the construction and use of the astrolabe is by al-Khwārizmī (9th C.), but the culmination of that tradition was al-Bīrūnī's great 11th C. treatise.[4]

The astrolabe is a portable model of the cosmos that can represent the positions of the sun and major stars at any time of the day or year for a given latitude. The rotating rete represents the heavens, and the plate, with its fixed celestial coordinate grid, represents the stationary earth. The observer orients himself with respect to the horizon, meridian, zenith, and pole star. Interchangeable plates for other latitudes could be carried inside the body of the astrolabe. The most useful aspect of the astrolabe is that, because of the way the celestial sphere is projected onto the plate, it can solve graphically many problems that would otherwise require spherical trigonometry.

The astrolabe on the right below once belonged to the 15th C. Timurid ruler, Ulugh Beg (1394-1449 C.E.), who was also an astronomer and mathematician.[5] On the left are examples from the Museum of the History of Science, Oxford, which has so many astrolabes, both Islamic and European, that you almost trip over them. Their online catalogue is very useful.[6]

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[2] King, David A. "Astrolabes, Quadrants, and Calculating Devices." In *Encyclopaedia of Islam, THREE*, edited by Kate Fleet, Gudrun Krämer, Denis Matringe, John Nawas and Everett Rowson: Brill Online, 2016.

[3] For a survey of Byzantine astrolabes, see: Tihon, Anne. "Traités byzantins sur l'astrolabe." *Physis* 32, (1995): 323-57.

[4] *Kitab fi istīʿāb al-wujūh fi ṣanʿat al-asṭurlāb*. See E. S. Kennedy,"al-Biruni." In *Dictionary of Scientific Biography*, 147-58. New York: Charles Scribner's Sons, 1970.

[5] http://www.davidmus.dk/en/collections/islamic/dynasties/timurids-and-turkmen/art/d_25-1986 . The catalogue states that this astrolabe was probably commissioned by Shah Rukh, Ulugh Beg's father. However, that makes little sense, unless he commissioned it for his son, who was the real student of astronomy.

[6] https://www.mhs.ox.ac.uk/astrolabe/catalogue/

Museum of the History of Science,
Oxford

Astrolabe belonging to Ulugh Beg
(15th C.), from The David Collection, Copenhagen

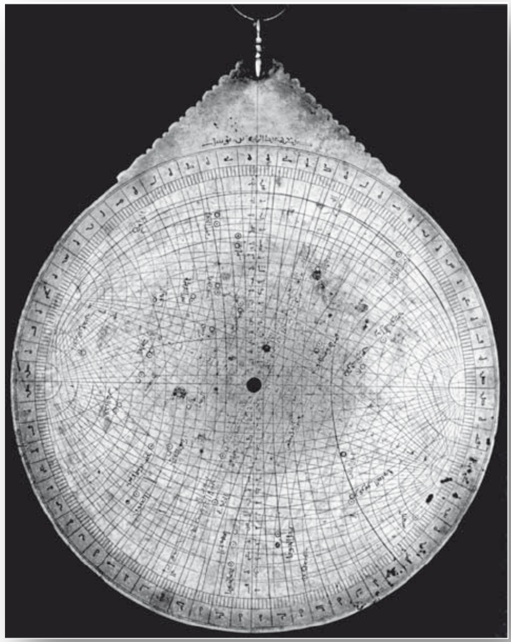
As stated earlier, the astrolabe was an important vector of the transmission of scientific knowledge to Europe. Below is the earliest extant astrolabe in medieval Europe,

the “Carolingian” astrolabe.[7] For some Europeans, such as Peter Abelard, it even symbolized the superiority of Arabic scientific culture.

Catalogue: Musée de l'Institut du monde arabe (Paris), Inventory number : AI 86-31

Although the astrolabe was originally a Greek invention, the Arabic tradition developed it to new heights of sophistication, just as it did with nearly everything else from Greek.[8] For example, on the left is the universal astrolabe plate invented by the 11th C. Andalusian Ibn al-Zarqālluh, which can be used for all latitudes. On the right is the 1328/29 C.E. masterpiece designed by Ibn al-Sarrāj in Aleppo. Said to have been the most sophisticated astrolabe ever made, it can be used universally in five different ways.[9]

[7] Discussed in detail in: King, David A. "The Earliest Known European Astrolabe in the Light of Other Early Astrolabes." In *The Oldest Latin Astrolabe*, edited by W. Stevens, G. Beaujouan and A. J. Turner, 359-404. Florence: Leo S. Olschki. Reprint, King, David A. *Astrolabes from Medieval Europe*, Variorum Collected Studies. Farnham, Surrey, UK: Ashgate, 2011.
[8] Neugebauer, O. "The Early History of the Astrolabe." *Isis* 40, no. 3 (1949): 240-56. Here, 240-241.
[9] King, *In Synchrony with the Heavens*, vol.2, 59-63.

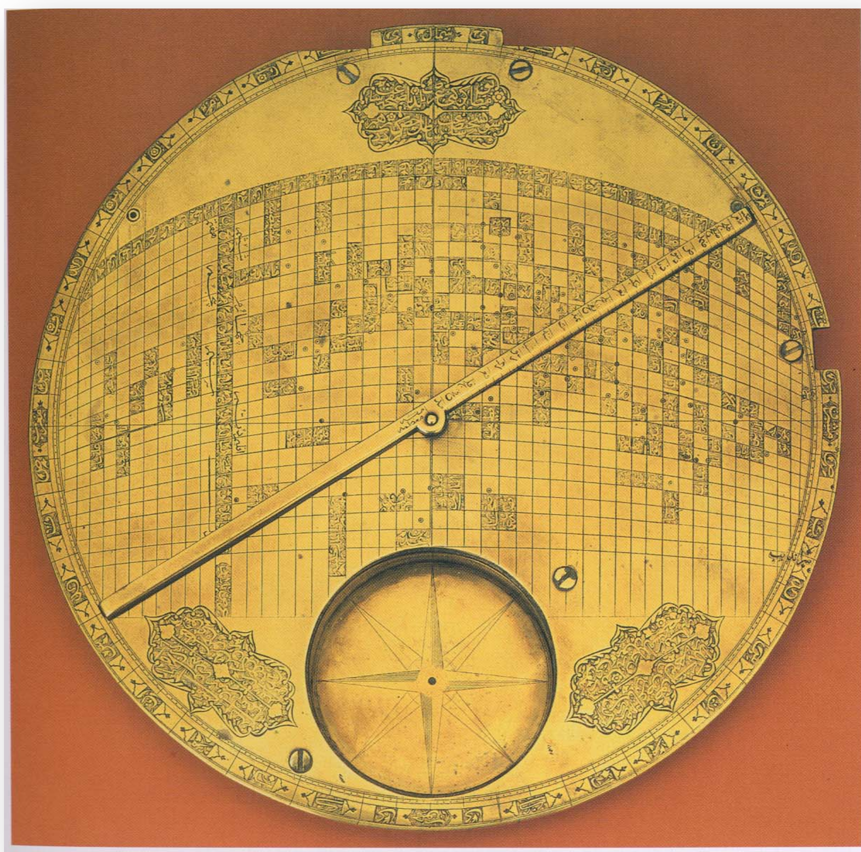


Universal plate of Ibn al-Zarqalluh (*shakkāziyya*)

The Most Sophisticated Astrolabe: Ibn al-Sarrāj
1328/29 C.E.

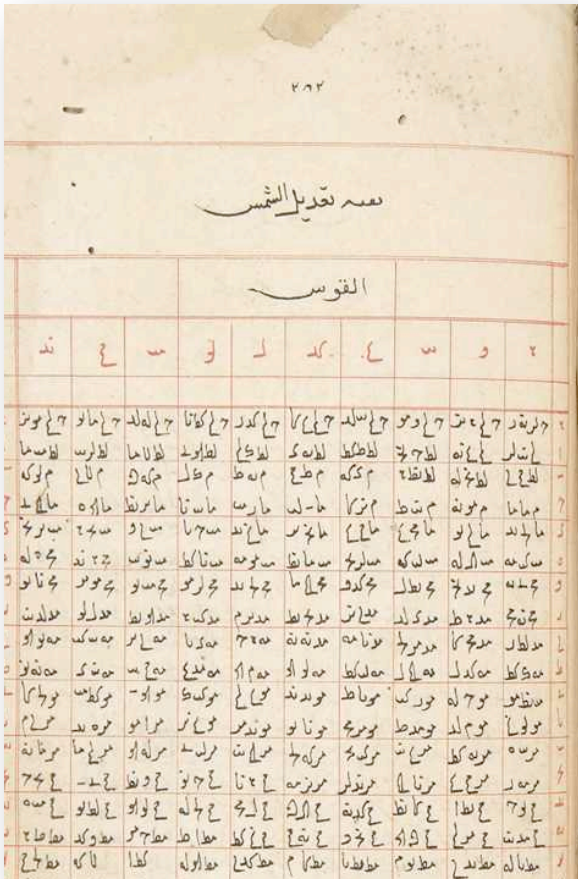
(Both images are from D. A. King. *In Synchrony with the Heavens: Studies in Astronomical Timekeeping and Instrumentation in Medieval Islamic Civilization. Volume Two: Instruments of Mass Calculation*. Leiden: E. J. Brill, 2005, pp. 59; 61.)

Astrolabes were only the beginning of ingenious instrument design in Islam. They are best known in the West because they were one of the intriguing devices brought back to Europe from the Muslim world in the 10th-11th Centuries, which spurred the Latins on to study math and astronomy. There were a host of other instruments for various purposes, most of which are known now only by their descriptions. An important exception is the universal qibla computer below, which we have heard about already today, whose projection of geography enables the nomographical determination of the sacred direction for many cities.[10]



From D. A. King. *World-Maps for Finding the Direction and Distance to Mecca: Innovation and Tradition in Islamic Science*. Leiden, 1999.

[10] It is itself based on math and prototypes developed much earlier in Islam. (King, *World-Maps,* pp.225-260).



Zīj Ulugh Beg, 1665 CE Indian copy (Christie's)[11] This section is a table of the equation (*taʿdīl*) of the Sun.

[11] *ZĪJ ULUGH BEG* (ASTRONOMICAL TABLES OF ULUGH BEG), SIGNED MUHAMMAD FATHULLAH BIN MUHAMMAD HUSAYN BAGRAMI, INDIA, DATED 19 RABI' II 1076/29 OCTOBER 1665 AD. Persian manuscript on paper, 223ff. as numbered plus two fly-leaves, most folios with tables in red and black, each with a title in black or red *naskh* script above, sections of text with 21-24ll. of black *naskh* script, occasional words picked out in red, others overlined in red, old repairs throughout, paginated, old seal impression of '*Mir 'Atiq devotee of Ahmad Shah Padshah Ghazi*' dated AH 1162, in pink cloth covered binding. Folio 9 1/8 x 5 ¼in. (23.2 x 13.1cm.) (From: http://www.christies.com/lotfinder/Lot/zij-ulugh-beg-astronomical-tables-of-ulugh-5826214-details.aspx)

A page from another zīj

Zījes were the earliest kind of astronomical text to be composed in Arabic. Called "zīj" because their characteristic form resembles a loom,[12] there were zīj traditions in Sanskrit and Pahlavi, which, along with Ptolemy's *Handy Tables*, influenced the Islamic tradition.[13] Zījes consisted of numerous kinds of tables and algorithms[14] for the computation of planetary positions, prayer times, and much more. They conveyed a great deal of astronomical knowledge, via the models that generated the tables, and the numerical parameters on which they were based.

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[12] For a discussion of the etymology, see: Kennedy, E. S. "A Survey of Islamic Astronomical Tables." *Transactions of the American Philosophical Society* 46, no. 2 (1956): 123-77; here, pp.123-124.

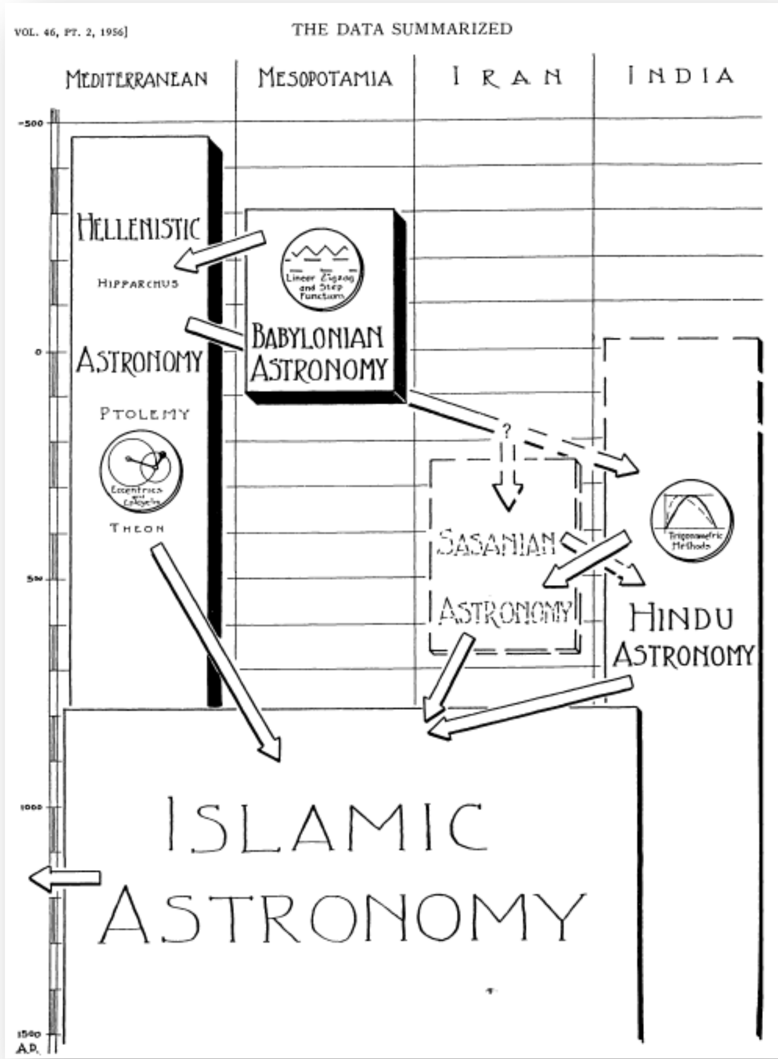
[13] Ptolemy. *Ptolemaiou Procheiroi Kanones. Ptolemy's Handy Tables, Volume 1b: Tables A1-A2. Transcription and Commentary by R. Mercier*, Publications de l'Institut Orientaliste de Louvain, 59B. Leuven: Peeters, 2011. Ibid., *Ptolemaiou Procheiroi Kanones. Les Tables Faciles de Ptolemee. Ptolemy's Handy Tables: Volume 1a: Tables A1-A2: Introduction. Edition Critique by Anne Tihon*, Publications de l'Institut Orientaliste de Louvain, 59B. Leuven: Peeters, 2011.

[14] This very useful word comes from the Arabic scientific tradition: the Latin form of Muḥammad ibn Mūsā al-Khwārizmī (d.c. 850 C.E.), the great Muslim algebraist.

Professor Kennedy's chart below shows the legacies of zījes between several cultures. The earliest known zīj that was of interest to Muslim astronomers was the *zīj al-Arkand*, an Arabic version of a Sanskrit original with Pahlavi sources, composed in Sind, 735 CE. The most important Indian zīj to be studied in Islam was the *Mahāsiddhanta*, translated by al-Fazārī as *Zīj al-Sindhind al-kabir*.[15] Al-Khwārizmī's *Zīj al-Sindhind* (not the same as al-Fazārī's translation) is the earliest non-fragmentary zīj to survive from the Arabic tradition, although it is extant only in Latin translation. The correction and improvement of zījes were justifications for the imperial sponsorship of observational astronomy. The first major such effort was Al-Ma'mūn's sponsored astronomical observations of 828-829 C.E., which resulted in a new zīj, corrected via new observations, the *al-Zīj al-Mumtaḥan* ("The verified zīj"), by Yaḥyā ibn Abī Manṣūr (d.832 C.E.).[16]

[15] Pingree, David. "The Fragments of the Works of al-Fazari." *Journal of Near Eastern Studies* 29, (1970): 103-23; here, 103.

[16] See Sayili, Aydin. *The Observatory in Islam: And its Place in the General History of the Observatory*. Vol. 38, Publications of the Turkish Historical Society Series. Ankara, Turkey: Turkish Historical Society, 1960. Reprint, Arno Press, New York, 1981, 50-87.



From: Kennedy, E. S. "A Survey of Islamic Astronomical Tables." *Transactions of the American Philosophical Society* 46, no. 2 (1956): 123-77

From Chaucer's Astrolabe Treatise (c.1391 CE)[17]

Geoffrey Chaucer (d. 1400) (*Canterbury Tales*), wrote this for his son, Louis. Comprehensive and clear, it could be used as a manual today. Students used astrolabes in their education to learn basic principles of math and astronomy (quadrivium). Chaucer was well aware of the Arabic origins of the astrolabe.

[17] See discussion in: Chism, Christine. "Transmitting the Astrolabe: Chaucer, Islamic Astronomy, and the Astrolabic Text." In *Medieval Textual Cultures: Agents of Transmission, Translation, and Transformation*, edited by Faitn Wallis and Robert Wisnovsky, 85-120. Berlin: De Gruyter, 2016.

When teaching the history of Islamic astronomy, showing diagrams of astrolabes and planetary models is too abstract for most students. Learning to use the tables helps them to better appreciate why the models were devised and refined. Moreover, assembling an astrolabe and learning how to calculate with it gives them deeper insight than any amount of reading can do.

Although instruction manuals survive, we know very little about how these tools were actually taught. Therefore, I decided to do an experiment in my history of Islamic science course this semester, in order to seek insights from a modern classroom experiment. In my course I am testing how a group of modern students, mostly innocent of astronomy, would learn to use these devices effectively, how much background knowledge would I need to provide, and how much would they be able to learn, not only about the ancient cosmos, but also about Islamic astronomy and its role in Islamic society, in particular. There are special challenges for 21st Century students, for: How many stars can you actually see in London or Los Angeles in the evening? And can it be taught within a semester? In effect, I am requiring that students practice seeing the cosmos from the point of view of the 9th Century Muslims, as much as possible. By this experiment I hope to shed light on the thesis that the astrolabe was an important vector of mathematical and astronomical knowledge to Europe, and that it was pregnant with learning implications.

While I plan eventually to generate my own plates and faces for astrolabes using my own computer programs and make them more Islamic in style, for now I use this website, which generates EPS files for the plates for your precise desired latitude, and provides a time correction for your longitude. The site is called "The Astrolabe Project". The author gives his name as "Richard Wymarc", which is a nom de plume of Timothy J. Mitchell. He has generously provided the program as a standalone web-based application.[18]

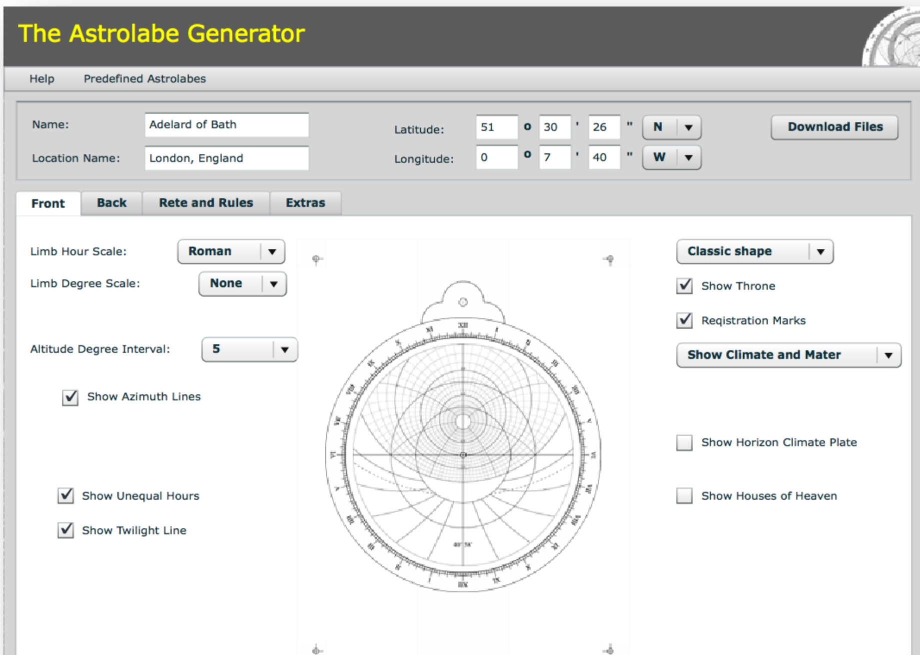
As you can see from these screenshots, the program allows you to customize your astrolabe by choosing between various features. The possible variations become very numerous with the back, since many options are provided, drawn from historical examples.

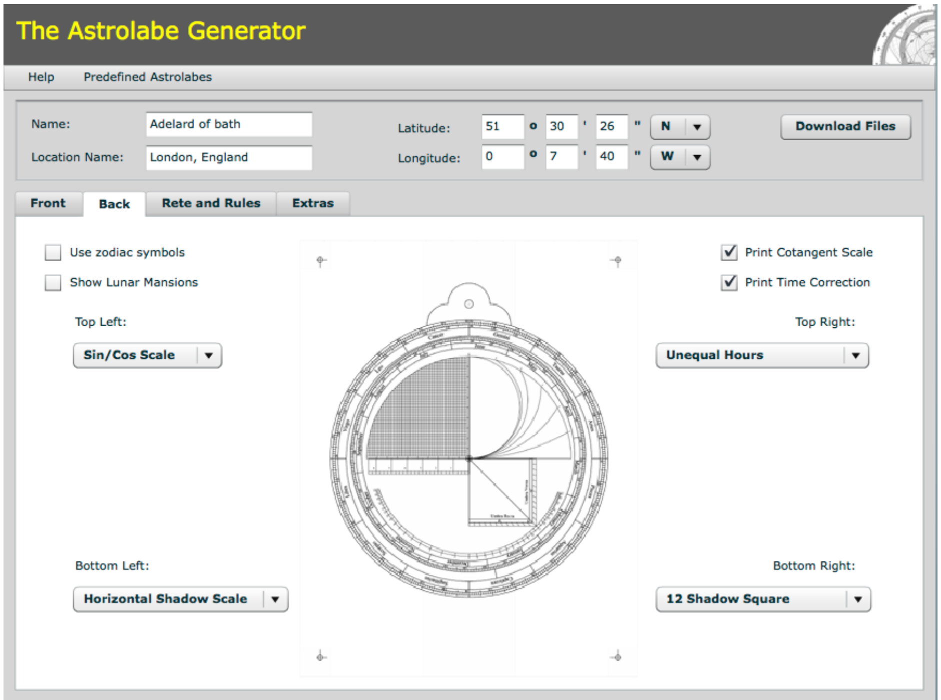
Here is my classroom demonstration model. It is set on paper glued to a Styrofoam board. See how all of the parts move. The only thing lacking is the sighting

[18] Mitchell also provides an instruction manual: http://astrolabeproject.com/downloads/Astrolabe_the_Missing_Manual.pdf

device that traditionally is found on the alidade. Because the paper astrolabe is relatively fragile, this feature is impractical. In future, I intend to construct a wooden model, and will include the sighting apparatus. I provide students with a file containing all of the pieces to print out on cardstock. The rete is printed on a transparent acetate sheet. The whole thing is assembled with a small screw and nut.

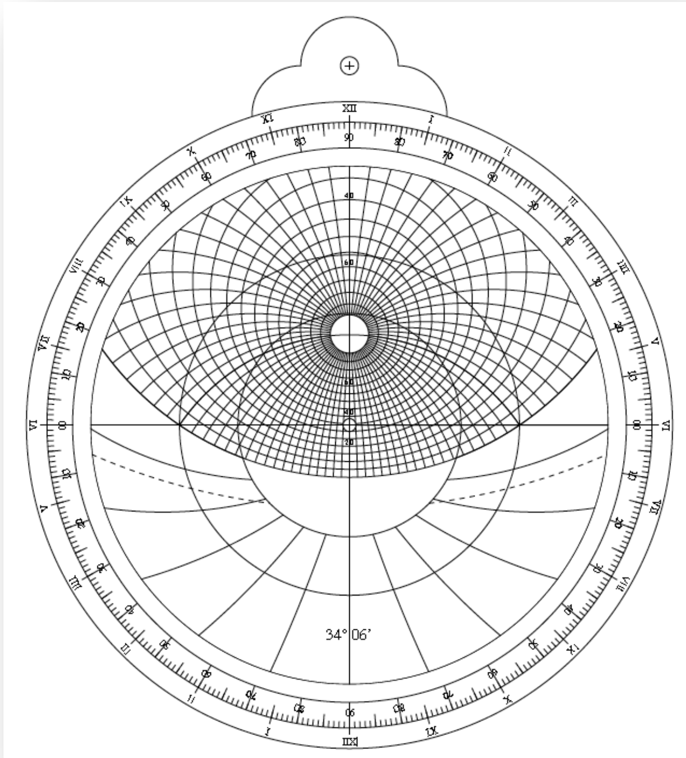
For now English is more useful than Arabic because most or all of my students do not know Arabic, and anyway all of these features are standard to many Islamic astrolabes.



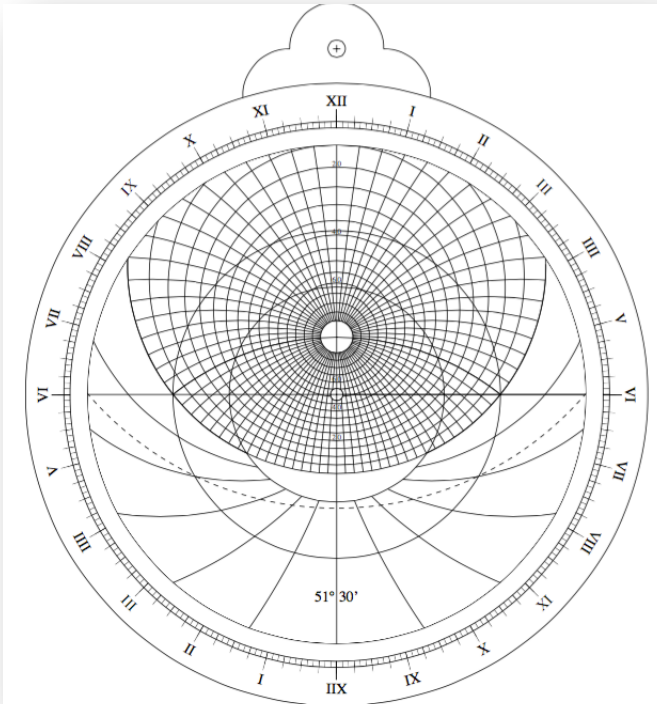


(http://astrolabeproject.com/build/astrolabe.html#app=c4ba&7ebb-selectedIndex=0)

Below are the front plates for London and Claremont, CA, where I live, and you can see how the difference in latitude affects the arcs. The horizon line runs up and down, bisecting the large circle, and this grid helps to locate objects in the sky.

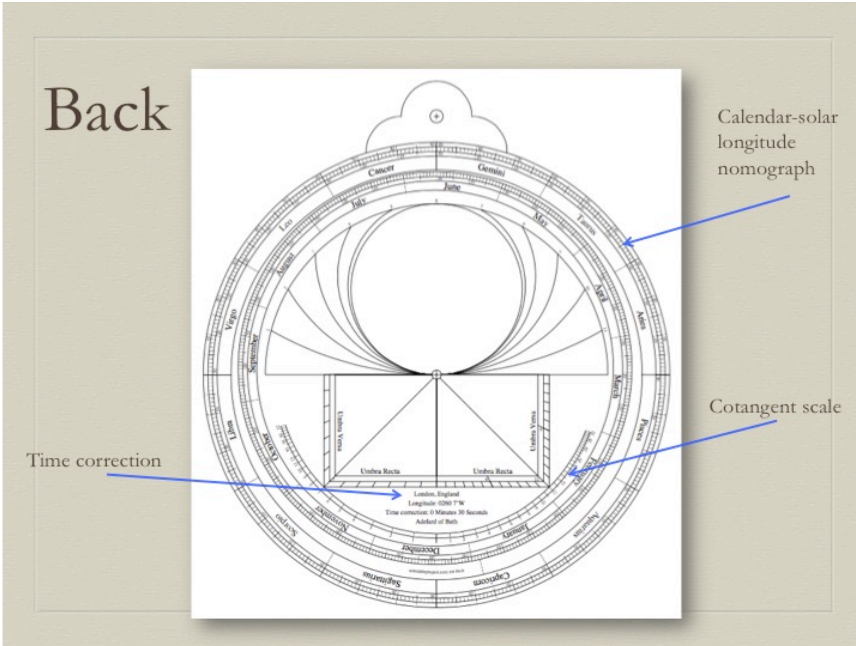


London, 51° 30’ N Latitude



Claremont, CA, 34° 6’ N Latitude

The back has a nomograph for converting between the civil calendar and the solar longitude in Zodiac coordinates, by aligning the alidade (the rule with the sighting tube). Another useful feature are the cotangent scales in the bottom half, which are used to convert a gnomon’s shadow length into an angle to determine the sun’s altitude.



The arcs and lines on the front plate can all be drawn using a straight edge and compass. That is an assignment for a higher level course. Professor Saliba had me do this in graduate school, and it was one of the most import things I ever did in my education. Both Evans and Morrison describe how to do this.[19]

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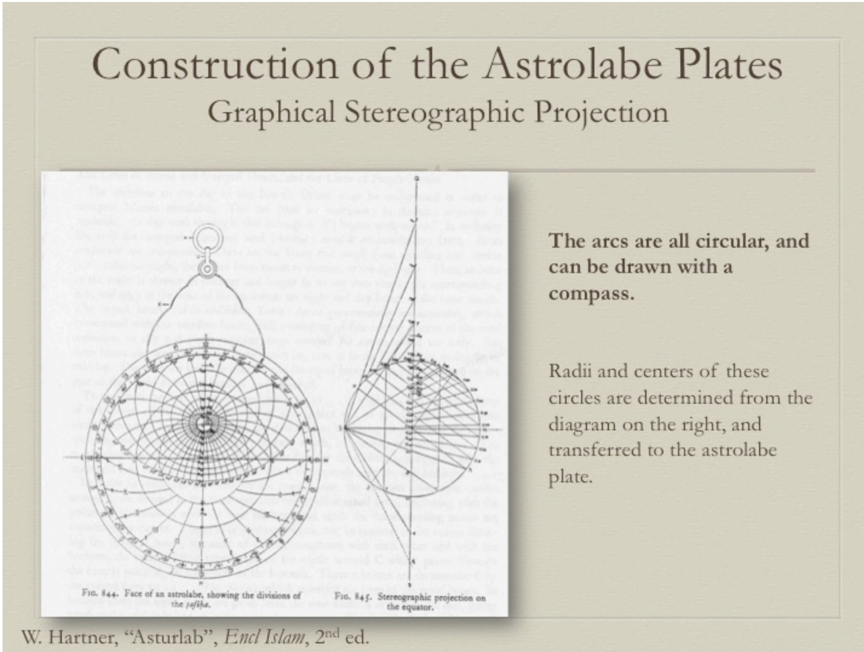
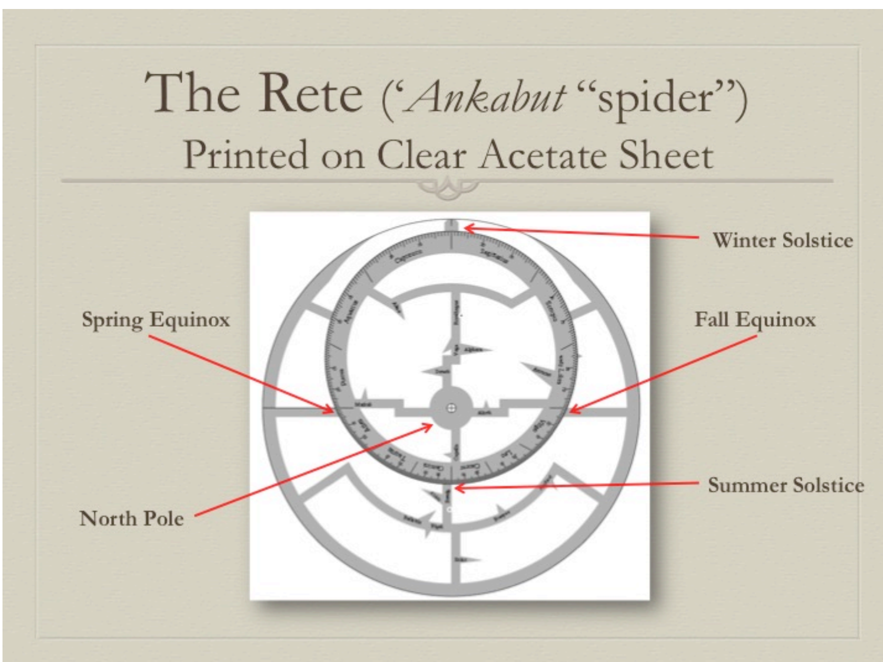
[19] Morrison, James E. *The Astrolabe*. Rehoboth Beach, DE, USA: Janus, 2007, pp.67-94.
Evans, James. *The History and Practice of Ancient Astronomy*. New York / Oxford: Oxford University Press, 1998, pp.158-161.

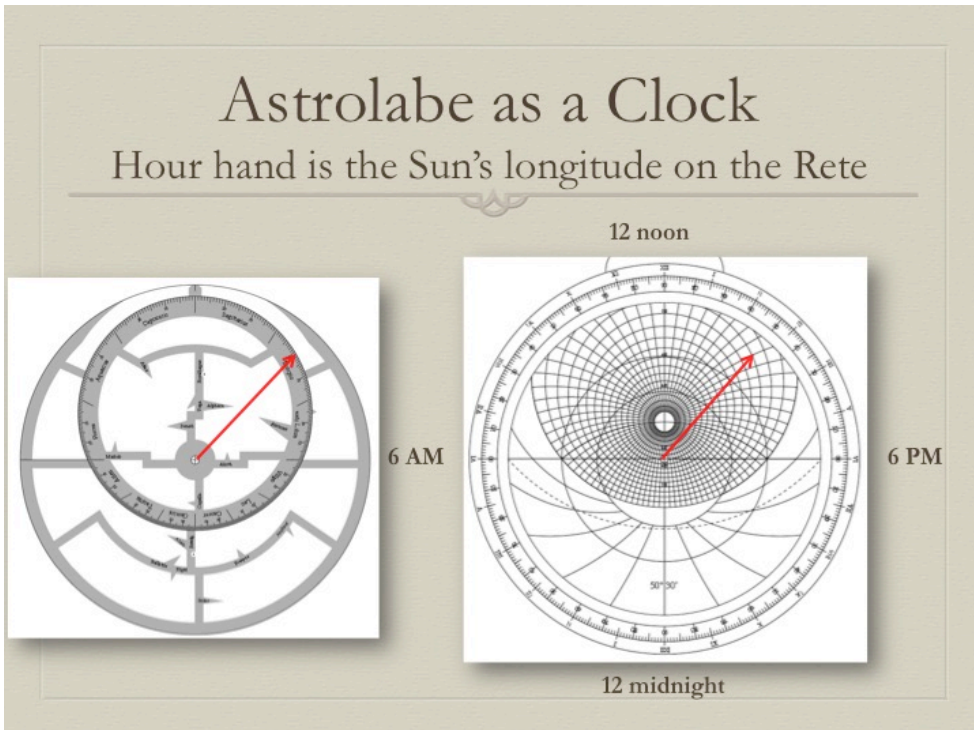


The rete ("net") contains the moving parts of the astrolabe, and by rotating it, one can mirror the state of the heavens at any time of day or night for any day of the year. Problems that would require spherical trigonometry are solved visually.

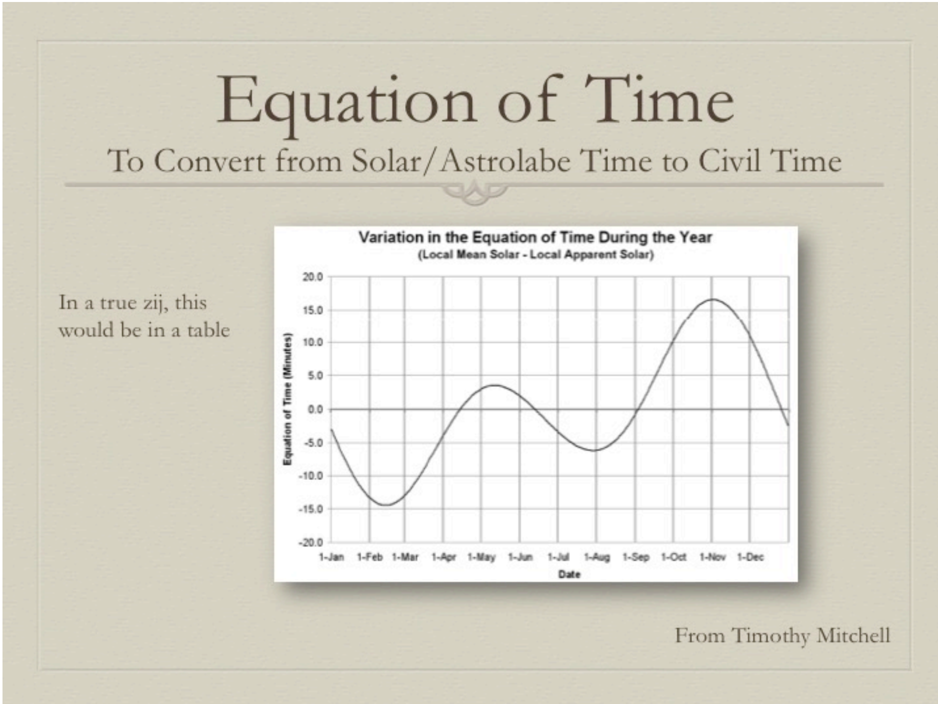


The first thing I do is to have the students locate the Sun on the ecliptic circle of the rete, for a given solar longitude. I ask them to imagine a little orange dot at that point, in order to keep the sun in mind as they rotate the rete in their calculations. After finding

the horizon, I show them how to trace the sun's arc through the day, from sunrise to sunset, noting how that arc is larger or smaller, depending on the season. The astrolabe is a kind of 24 hour clock. Then I ask them how they would find the time of sunrise. The answer is to align the sun and the rule at the eastern horizon, and read the time of sunrise from the outer scale. Students grasp this fairly easily. I next ask them how far north or south of due east will the sun rise? They use the azimuth lines to determine the degree difference between the Sun's rising point and due east.



The times they find are local apparent solar time, which are different from clock time, so I show them how to use the Equation of Time and the Time Zone Correction to get clock time. For now they use a graph like this one below. A real zīj has a table like the following, which I've created to be an excerpt from a "modern" zīj.



Equation of Time Table from a "Modern zīj" (excerpt)

Day Number	Calendar date	Equation of Time
1	Jan 1	-4 m 34 s
2	Jan 2	-4 m 59 s
3	Jan 3	-5 m 24 s
4	Jan 4	-5 m 49 s
5	Jan 5	-6 m 13 s
6	Jan 6	-6 m 37 s
7	Jan 7	-7 m 0 s
8	Jan 8	-7 m 23 s
9	Jan 9	-7 m 46 s
10	Jan 10	-8 m 8 s
11	Jan 11	-8 m 29 s
12	Jan 12	-8 m 50 s
13	Jan 13	-9 m 10 s
14	Jan 14	-9 m 30 s
15	Jan 15	-9 m 49 s

After students have practiced with rising and setting times, finding the Ascendant, and telling time from the Sun's (or a star's) altitude, they are ready to calculate Islamic prayer times. Since this is a history of Islamic science course, they already know what these are and why they are important. I have them fill out this chart for a given day. Four of the prayer times are straightforward and can be determined using the front of the astrolabe, by positing the Sun in the appropriate position. The Salat al-'Asr, the afternoon

prayer, however, is more complicated, since it is defined as the time when the sun's shadow equals the length of the gnomon plus the shadow length at noon.[20]

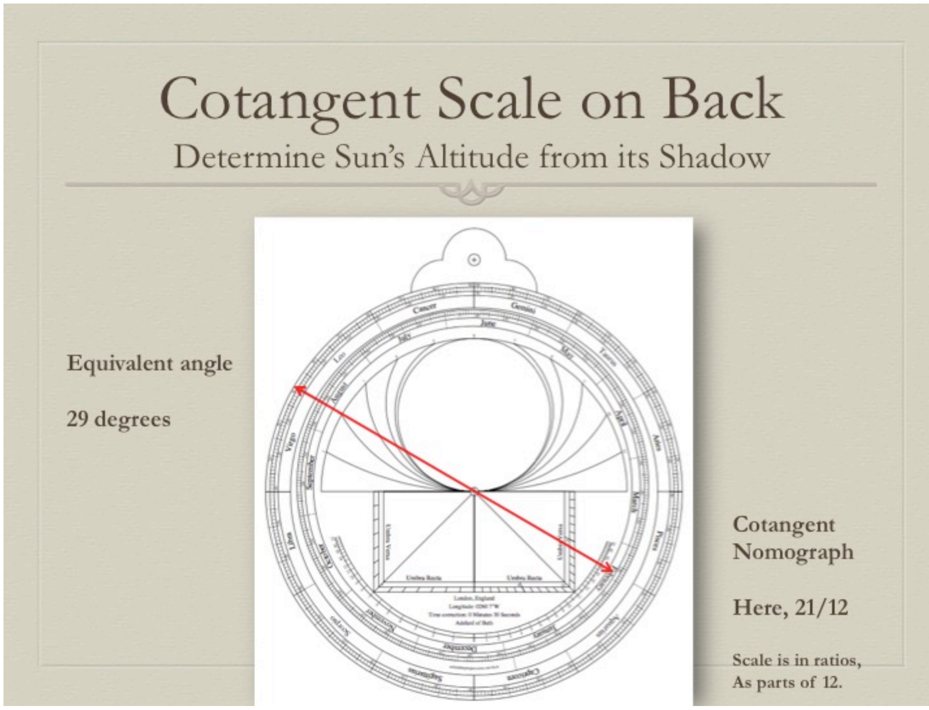
Islamic Prayer Times Exercise **Name**__________

Instructions: Use your astrolabe to complete this chart. Fill in the colı corresponding to the bolded terms in Column 2.

Prayer	Definition	Date 1	
Solar Longitude	(Use astrolabe back to determine)		
صلاة الفجر *Ṣalāt al-fajr*	Begins at **dawn**		
	Ends at **sunrise**		
صلاة الظهر *Ṣalāt al-ẓuhr*	Begins at **noon**		
	Ends at ***Ṣalāt al-ʿaṣr***		
صلاة العصر *Ṣalāt al-ʿaṣr*	Begins when an object's shadow equals its own length plus its length at noon (*majority view*) (Use the **special procedure on the handout**)		
	Ends at **sunset**		
صلاة المغرب *Ṣalāt al-maġrib*	Begins at **sunset**		
	Ends at **twilight**		
صلاة العشاء *Ṣalāt al-ʿišāʾ*	Begins at **twilight**		
	Ends at **dawn** (next day)		

The cotangent nomograph is used to convert gnomon ratios to angles and vice versa.

[20] This is one accepted definition. The others can all be calculated with the astrolabe in a similar manner.

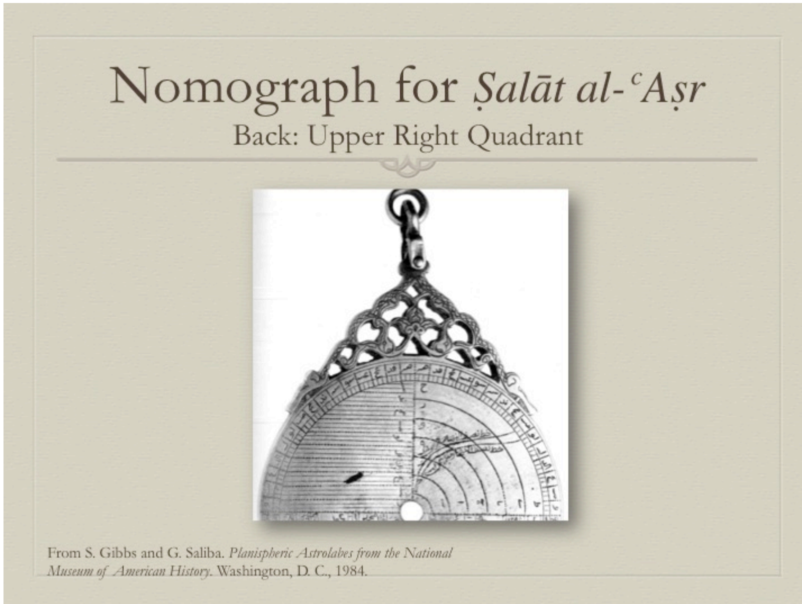


So, to determine the starting time of Salat al-‘Asr, I have them fill out the following chart, an algorithm that employs the cotangent scale. This prayer time requires them to do two iterations of cotangents and arccotangents.

CALCULATING *ṢALĀT AL-ʿAṢR* USING THE ASTROLABE **NAME**________________________
Worksheet (using the majority method)

STEPS	RESULT 1	RESULT 2
GIVEN CALENDAR DATE:		
DETERMINE THE SOLAR LONGITUDE FOR THE DATE. Using the calendar scale on the back of the astrolabe.		
DETERMINE THE ALTITUDE OF THE SUN AT NOON. Align the point on the ecliptic circle corresponding to solar longitude with the Meridian line. Read off the solar altitude from the almucantar circle (in degrees).		
DETERMINE THE COTANGENT OF THIS ANGLE. On the back of the astrolabe, using one of the upper quadrant angles scales, align the alidade with the noon solar altitude angle that you just found. Read the number from the **Cotangent Scale** at the other end of the alidade, as a factor of 7 or 12, depending on the scale you choose. (This will be a whole number for purpose of this scale). Add 12 to this number.	 **+ 12 =**	 **+ 12 =**
FIND THE ARCCOTANGENT (INVERSE COTANGENT) OF THIS NUMBER by reversing the procedure you just followed. I.e. align the alidade with this new number on the Cotangent Scale, and read off the angle from the opposite quadrant scale, from the other end of the alidade. The result is the **altitude of the sun in the afternoon when *ṣalāt al-ʿasr* is to begin**.		
NOW DETERMINE THE TIME CORRESPONDING TO THIS ALTITUDE. On the front of the astrolabe align the solar longitude point with the almucantar corresponding to the solar altitude *in the afternoon* quadrant, and read the time from the hour scale. This is the **time when *ṣalāt al-ʿasr* is to begin according to *local apparent solar time***.		
CONVERT THIS TIME TO CLOCK TIME		
If **Daylight Savings Time** is in effect, then **add 1 hour**.		
Subtract the value of the **Equation of Time** for the given date. (**E of T value =** ________________)		
Add the **Time Zone Correction** (printed on the back of your astrolabe). (**TZC =** ______________________) THE RESULT IS THE ***CLOCK*** **TIME WHEN *ṢALĀT AL-ʿASR* IS TO BEGIN**.		

This algorithm enables students to do with greater precision what this nomograph on the back of the astrolabe below was meant to do. Using an astrolabe for determining prayer times may not have been common, when prayer times were commonly available in tables. But it is a convenient backup method.



In all, my students have learned to perform all of these operations with their astrolabes:

- **Time of day** from the sun’s shadow
- **Time of night** from a star’s elevation
- Time of **sunrise** and **sunset**
- **Rising and setting times** of significant stars (Arcturus and Sirius)
- Length of **daylight**
- Determining equinoctial and seasonal hours
- Azimuthal deviation sun’s rising and setting from due east and west
- Sun’s altitude at noon
- The **Ascendant, Midheaven, Descendant**, and the **Lower Heaven** (Imum Caeli), astrologically useful points
- Use of **cotangent scale** to infer elevation angle from shadow length
- Determination of **Islamic prayer times**, especially the complicated **Salat al-‘Asr**

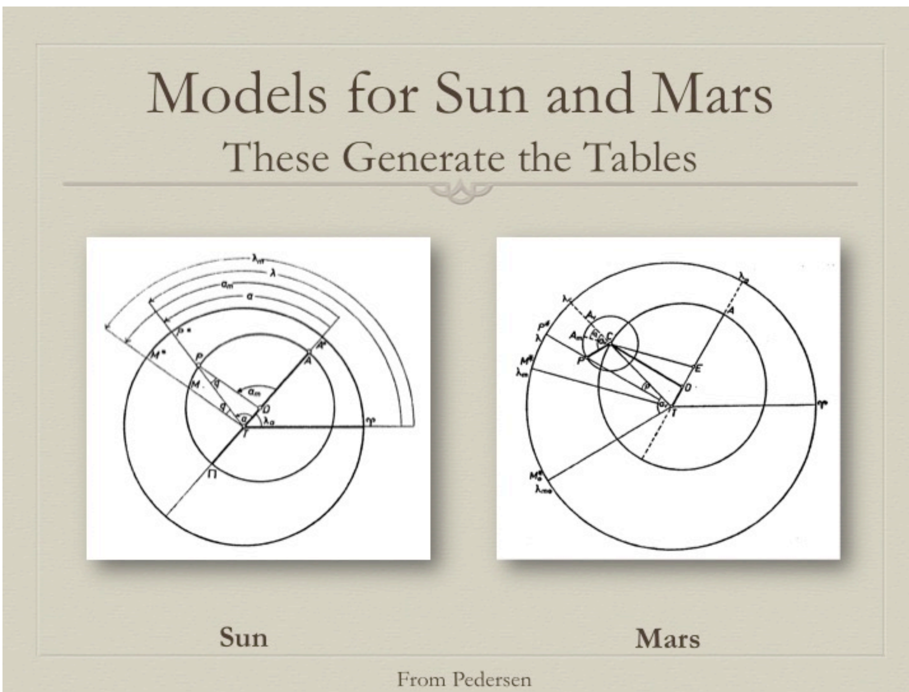
These are just some of the possible uses of the astrolabe. Many more are described in the Arabic manuals.

Learning to use Zīj Planetary Tables

When I was a graduate student, Professor Saliba had me construct an astrolabe from scratch, and work through the mathematics behind Ptolemy’s planetary models. However, because I can’t require all that of students in a history survey course, there are

books by Pedersen and Evans that have provided helpful shortcuts.[21]

I teach studnets how the basic planetary models were derived, and how their parameters were determined from observation, noting the physical impossibility of the Equant point in the model for Mars. I explain that they will first determine the approximate position of the planet by using the mean motion tables, and then adjust it more precisely using “equation” tables, all by addition and subtraction. This is done instead of using trigonometry, which has already been done by the zīj compiler. Since this assignment is integrated with the history of Islamic astronomy unit, they learn about the critique and improvement of Ptolemy’s models by Muslim astronomers. Moreover, a similar technique is still used today in applied mathematics, for example, when finding approximate solutions of differential equations.



Then I introduce them to the three Zīj-Tables that they will use to determine the solar equation. They are: The table of mean motions, the table of the solar apogee, and the table of the solar equation.

[21] Evans, James. *The History and Practice of Ancient Astronomy*. New York / Oxford: Oxford University Press, 1998. Pedersen, Olaf. *A Survey of the Almagest. With Annotation and New Commentary by Alexander Jones*. Revised ed, Sources and Studies in the History of Mathematics and Physical Sciences. New York: Springer, 2011.

MEAN LONGITUDE OF SUN, TIME INCREMENTS

DAYS	LONGITUDE	DAYS	LONGITUDE	DAYS	LONGITUDE
100,000	284° 44.0'	**10,000**	136° 28.4'	**1,000**	265° 38.9'
200,000	209° 28.0'	**20,000**	272° 56.8'	**2,000**	171° 17.8'
300,000	134° 12.0'	**30,000**	49° 25.2'	**3,000**	76° 56.6'
400,000	58° 56.0'	**40,000**	185° 53.6'	**4,000**	342° 35.5'
500,000	343° 40.1'	**50,000**	322° 22.0'	**5,000**	248° 14.4'
600,000	268° 24.1'	**60,000**	98° 50.4'	**6,000**	153° 53.0'
700,000	193° 08.1'	**70,000**	235° 18.8'	**7,000**	59° 31.9'
800,000	117° 52.1'	**80,000**	11° 47.2'	**8,000**	325° 10.7'
900,000	42° 36.1'	**90,000**	148° 15.6'	**9,000**	230° 49.6'
100	98° 33.9'	**10**	9° 51.4'	**1**	0° 59.1'
200	197° 7.8'	**20**	19° 42.8'	**2**	1° 58.3'
300	295° 41.7'	**30**	29° 34.2'	**3**	2° 57.4'
400	34° 15.6'	**40**	39° 25.6'	**4**	3° 56.6'
500	132° 49.4'	**50**	49° 16.9'	**5**	4° 55.7'
600	231° 23.3'	**60**	59° 08.3'	**6**	5° 54.8'
700	329° 57.2'	**70**	68° 59.7'	**7**	6° 54.0
800	68° 31.1'	**80**	78° 51.1'	**8**	7° 53.1'
900	167° 05.0'	**90**	88° 42.5'	**9**	8° 52.2'

HOURS	LONGITUDE	HOURS	LONGITUDE	MINUTES	LONGITUDE
1	0° 02.5'	**13**	0° 32.0'	**10**	0° 0.4'
2	0° 04.9'	**14**	0° 34.5'	**20**	0° 0.8'
3	0° 07.4'	**15**	0° 37.0'	**30**	0° 1.2'
4	0° 09.8'	**16**	0° 39.4'	**40**	0° 1.6'
5	0° 12.3'	**17**	0° 41.9'	**50**	0° 2.1'
6	0° 14.8'	**18**	0° 44.4'	**60**	0° 2.5'
7	0° 17.2'	**19**	0° 46.8'		
8	0° 19.7'	**20**	0° 49.3'		
9	0° 22.2'	**21**	0° 51.7'		
10	0° 24.6'	**22**	0° 54.2'		
11	0° 27.1'	**23**	0° 56.7'		
12	0° 29.6'	**24**	0° 59.1'		

Table of the Longitude of the Solar Apogee (adapted from Evans, p.228)

YEAR	LONGITUDE	YEAR	LONGITUDE	YEAR	LONGITUDE	10-YEAR INTERVALS	MOTION
801 B.C.	53°57'	200 A.D.	71°25'	1200 A.D.	88°53'	10	0°10'
701	55°42'	300	73°10'	1300	90°38'	20	0°21'
601	57°27'	400	74°55'	1400	92°23'	30	0°31'
501	59°12'	500	76°40'	1500	94°8'	40	0°42'
401	60°57'	600	78°24'	1600	95°53'	50	0°52'
301	62°41'	700	80°09'	1700	97°37'	60	1°03'
201	64°26'	800	81°54'	1800	99°21'	70	1°13'
101	66°11'	900	83°39'	1900	101°06'	80	1°24'
1 B.C.	67°56'	1000	85°23'	2000	102°51'	90	1°34'
100 A.D.	69°40'	1100	87°08'	2100	104°36'		

Table of the Equation of Center of the Sun (adapted from Evans, p.229)

MEAN ANOMALY	EQUATION OF CENTER	MEAN ANOMALY	EQUATION OF CENTER
0° (360)	-(+) 0°0'	90° (270)	-(+) 1°55'
5° (355)	0°10'	95° (265)	1°55'
10° (350)	0°19'	100° (260)	1°54'
15° (345)	0°29'	105° (255)	1°52'
20° (340)	0°38'	110° (250)	1°49'
25° (335)	0°47'	115° (245)	1°46'
30° (330)	0°56'	120° (240)	1°41'
35° (325)	1°04'	125° (235)	1°36'
40° (320)	1°12'	130° (230)	1°30'
45° (315)	1°19'	135° (225)	1°23'
50° (310)	1°26'	140° (220)	1°16'
55° (305)	1°32'	145° (215)	1°08'
60° (300)	1°38'	150° (210)	0°59'
65° (295)	1°43'	155° (205)	---
70° (290)	1°47'	160° (200)	---
75° (285)	1°50'	165° (195)	---
80° (280)	1°52'	170° (190)	---
85° (275)	1°54'	175° (185)	---
90° (270)	1°55'	180° (180)	---

Below is the algorithm they follow. This chart covers every step with an explanation. First they compute the Sun's mean position, and then adjust it with the equation from this table. The spreadsheet does the sexagesimal arithmetic for them. I have previously taught them how to do all of the operations in sexagesimal, but decided that it would be too much to make them do all of it in base 60.

Calculate the days between Epoch and your date					
Date			Time Zone		
Year	Month		Day	Time	L
1996	1		1		
Julian Day Number			2450083		
Difference in days				35063	

Use the Longitude tables to find the change in Mean Longitude			
Time Element (Number of Days)		Increment (mean longitude)	
		Degrees	Minutes
100,000s			
10,000s			
1000s			
100s			
10s			
1s			
Hours			
Minutes (10 min. increments)			
Result: The total **change in Sun's mean motion** since Epoch		0	0
Add the **Mean Value at Epoch**.		279	42
Result: The **Mean Longitude**, and the **Mean Epicyclic Anomaly** of the planet at the given time		279	42
		Total Mean Longitude	

Determine the Longitude of the Apogee			
		Degrees	Minutes
Use the century year immediately before the given year, and get the result (**Use the chart**)			
Add the value for the difference between the century year and the given year, to the nearest decade			
Result: **Longitude of the Solar Apogee**		0	0
		Longitude of the Solar Apogee	

Calculate the Mean Anomaly			
		Degrees	**Minutes**
From the Mean Longitude			
Subtract the **Longitude of the Apogee**			
Result: **Mean Anomaly** (if < 0, add 360°)		**0**	**0**

Determine the Equation of Center			
		Degrees	**Minutes**
Using **Mean Anomaly** as the argument, get **Equation of Center** (q) from **Table 5.3**		**12**	**3**
If **Mean Anomaly** is between 0° and 180°, then **Equation of Center** is negative (Add - sign ***to both Degrees and Minutes***)			
If **Mean Anomaly** is between 180° and 360°, then **Equation of Center** is positive.			

Calculate Solar Longitude			
		Degrees	**Minutes**
Add: **Mean Longitude**			
to: Equation of Center			
Result: **Longitude of the Sun**		**0**	**0**

Sun's Position on the Zodiac

Instructions for Using the Solar Longitude Spreadsheet

Step 1: Insert your date in **line 1**. The **difference in days** is in **line 2.**

Step 2: Take the **difference in days** number, and write it as digits and powers of ten, e.g. write 23456 as: 2*10000 + 3*1000 + 4*100 + 5*10 + 6

Step 3: Take each of these number elements and consult the **Mean Longitude of Sun** table, and take out the angle corresponding to it, and input it into the row of the spreadsheet corresponding to that power of ten (lines 3-10). All of these increments will add up and the sum will appear in **line 11**. The program will automatically add the mean value of the solar longitude at Epoch for you, and the result will appear in **line 13**. You will need this Mean Longitude twice more in the spreadsheet.

Step 4: Consult **Table 5.2 Longitude of the Solar Apogee**, following the instructions on **line 14**. Take out the Longitude of the Apogee, and input it in **line 14**. Take from the table also the apogee increment to the nearest decade, from the rightmost column. The result will appear in **line 16**, this is the **Longitude of the Solar Apogee**.

Step 5: Get the **Mean Longitude** from **line 13**, and input it into **line 17**. Get the **Longitude of the Solar Apogee** from **line 16**, and input it into **line 18**. The result is the **Mean Anomaly**, which will appear in **line 19**.

Step 6: Use the **Mean Anomaly** as the argument, and consult **Table 5.3 Equation of the Center of the Sun**. Find the nearest value in the column, and take out the corresponding vale from the right column. That is the absolute value of the **Equation of Center**. Put it into **line 20**. To determine its sign (+/-) follow the instructions in **lines 20a** and **20b**. If the **Equation of Center** is negative, then put a negative sign in front of BOTH DEGREES and MINUTES.

Step 7: From **line 13**, put the **Mean Longitude** into **line 21**. And from **line 20**, put the **Equation of Center** into **line 22**. The result will be the Sun's longitude for your date and time.

Step 8: Determine the Zodiac Sign and Degree. Using the **Signs and their Degrees Longitude Chart**, follow the instructions to find k. Use k to find the Zodiac Sign in which the Sun is found. The remainder is the degree in that Sign. So, e.g. if your Solar Longitude came out to be 319 degrees and 17.5 minutes, k is 10, and the remainder is 19 degrees, 17.5 minutes. So your Sign is Aquarius. The **Sun's position** is then Aquarius 19 degrees, 17.5 minutes. Type that into **line 24** of the spreadsheet.

Step 9: Print out your spreadsheet, ***and save it***. Hand the printout in to me on Tuesday.

Once they have mastered the solar equation, they are ready to tackle the upper planet, Mars, which requires them to determine **two mean motions and two equations**, one for the center of the epicycle and one for Mars's position on the epicycle. These tables are more complicated …

MEAN LONGITUDE AND MEAN EPICYCLIC ANOMALY OF MARS, TIME INCREMENTS

DAYS	LONGITUDE	EPICYCLIC ANOMALY	DAYS	LONGITUDE	EPICYCLIC ANOMALY	DAYS	LONGITUDE	EPICYCLIC ANOMALY
100,000	207° 7.0'	77° 37.1'	**10,000**	200° 42.7'	295° 45.7'	**1,000**	164° 4.3'	101° 34.6'
200,000	54° 13.9'	155° 14.2'	**20,000**	41° 25.4'	231° 31.4'	**2,000**	328° 8.5'	203° 9.1'
300,000	261° 20.9'	232° 51.2'	**30,000**	242° 8.1'	167° 17.1'	**3,000**	132° 12.8'	304° 43.7'
400,000	108° 27.8'	310° 28.3'	**40,000**	82° 50.8'	103° 2.8'	**4,000**	296° 17.1'	46° 18.3'
500,000	315° 34.8'	28° 5.4'	**50,000**	283° 33.5'	38° 48.5'	**5,000**	100° 21.3'	147° 52.9'
600,000	162° 41.8'	105° 42.5'	**60,000**	124° 16.2'	334° 34.2'	**6,000**	264° 25.6'	249° 27.4'
700,000	9° 48.7'	183° 19.6'	**70,000**	324° 58.9'	270° 20.0'	**7,000**	68° 29.9'	351° 2.0'
800,000	216° 55.7'	260° 56.6'	**80,000**	165° 41.6'	206° 5.7'	**8,000**	232° 34.2'	92° 36.6'
900,000	64° 2.6'	338° 33.7'	**90,000**	6° 24.3'	141° 51.4'	**9,000**	36° 38.4'	194° 11.1'
100	52° 24.4'	46° 9.5'	**10**	5° 14.4'	4° 36.9'	**1**	0° 31.4'	0° 27.7'
200	104° 48.9'	92° 18.9'	**20**	10° 28.9'	9° 13.9'	**2**	1° 2.9'	0° 55.4'
300	157° 13.3'	138° 28.4'	**30**	15° 43.3'	13° 50.8'	**3**	1° 34.3'	1° 23.1'
400	209° 37.7'	184° 37.8'	**40**	20° 57.8'	18° 27.8'	**4**	2° 5.8'	1° 50.8'
500	262° 2.1'	230° 47.3'	**50**	26° 12.2'	23° 4.7'	**5**	2° 37.2'	2° 18.5'
600	314° 26.6'	276° 56.7'	**60**	31° 26.7'	27° 41.7'	**6**	3° 8.7'	2° 46.2'
700	6° 51.0'	323° 6.2'	**70**	36° 41.1'	32° 18.6'	**7**	3° 40.1'	3° 13.9'
800	59° 15.4'	9° 15.7'	**80**	41° 55.5'	36° 55.6'	**8**	4° 11.6'	3° 41.6'
900	111° 39.8'	55° 25.1'	**90**	47° 10.0'	41° 32.5'	**9**	4° 43.0'	4° 9.3'

HOURS	LONGITUDE	EPICYCLIC ANOMALY	HOURS	LONGITUDE	EPICYCLIC ANOMALY	MINUTES	LONGITUDE	EPICYCLIC ANOMALY
1	0° 1.3'	0° 1.2'	**13**	0° 17.0'	0° 15.0'	**10**	0° 0.2'	0° 0.2'
2	0° 2.6'	0° 2.3'	**14**	0° 18.3'	0° 16.2'	**20**	0° 0.4'	0° 0.4'
3	0° 3.9'	0° 3.5'	**15**	0° 19.7'	0° 17.3'	**30**	0° 0.7'	0° 0.6'
4	0° 5.2'	0° 4.6'	**16**	0° 21.0'	0° 18.5'	**40**	0° 0.9'	0° 0.8'
5	0° 6.6'	0° 5.8'	**17**	0° 22.3'	0° 19.6'	**50**	0° 1.1'	0° 1.0'
6	0° 7.9'	0° 6.9'	**18**	0° 23.6'	0° 20.8'	**60**	0° 1.3'	0° 1.2'
7	0° 9.2'	0° 8.1'	**19**	0° 24.9'	0° 21.9'			
8	0° 10.5'	0° 9.2'	**20**	0° 26.2'	0° 23.1'			
9	0° 11.8'	0° 10.4'	**21**	0° 27.5'	0° 24.2'			
10	0° 13.1'	0° 11.5'	**22**	0° 28.8'	0° 25.4'			
11	0° 14.4'	0° 12.7'	**23**	0° 30.1'	0° 26.5'			
12	0° 15.7'	0° 13.8'	**24**	0° 31.4'	0° 27.7'			

Table of the Longitude of the Martian Apogee (adapted from Evans, p.375)

YEAR	LONGITUDE	YEAR	LONGITUDE	YEAR	LONGITUDE	10 YEAR PERIODS	MOTION
801 B.C.	99°34'	200 A.D.	117°38'	1200 A.D.	135°42'	10	0°11'
701	101°23'	300	119°26'	1300	137°30'	20	0°22'
601	103°11'	400	121°15'	1400	139°18'	30	0°33'
501	105°00'	500	123°03'	1500	141°07'	40	0°43'
401	106°48'	600	124°51'	1600	142°55'	50	0°54'
301	108°36'	700	126°40'	1700	144°43'	60	1°05'
201	110°25'	800	128°28'	1800	146°32'	70	1°16'
101	112°13'	900	130°16'	1900	148°20'	80	1°27'
1 B.C.	114°01'	1000	132°05'	2000	150°08'	90	1°38'
100 A.D.	115°50'	1100	133°53'	2100	151°57'		

Table of Equations for Mars (adapted from Evans, p.375)

Common Argument	Equation of Center	Equation of the Epicycle (Argument μ) Diminution at Apogee	Equation at mean Distance	Augmentation at Perigee	Interpolation Coefficient (Arg α bar)
0° (360)	-(+) 0°00'	0'	-(+) 0°00'	0'	Dim 1.000
5° (355)	0°56'	07'	1°59'	08'	0.998
10° (350)	1°51'	14'	3°58'	16'	0.990
15° (345)	2°46'	21'	5°56'	24'	0.978
20° (340)	3°40'	28'	7°54'	32'	0.961
25° (335)	4°33'	35'	9°52'	40'	0.939
30° (330)	5°24'	43'	11°49'	48'	0.911
35" (325)	6°13'	50'	13°45'	57'	0.879
40° (320)	7°00'	58'	15°41'	65'	0.841
45° (315)	7°44'	65'	17°35'	74'	0.799
50° (310)	8°26'	73'	19°28'	83'	0.750
55° (305)	9°04'	82'	21°20'	93'	0.697
60° (300)	9°39'	90'	23°10'	103'	0.638
65° (295)	10°10'	99'	24°58'	113'	0.573
70° (290)	10"37'	109'	26°44'	124'	0.504
75° (285)	11°00'	118'	28°27'	136'	0.428
80° (280)	11°18'	129'	30°07'	148'	0.348
85° (275)	11°32'	140'	31°44'	161'	0.262
90° (270)	11°41'	151'	33°17'	175'	0.171
95° (265)	11°45'	163'	34°44'	189'	Dim 0.075
100° (260)	11°43'	176'	36°07'	205'	Aug 0.019
105° (255)	11°23'	190'	37°22'	223'	0.096
110° (250)	11°36'	205'	38°30'	241'	0.176
115° (245)	11°05'	221'	39°27'	262'	0.258
120° (240)	10°41'	238'	40° 14'	284'	0.340
125° (235)	10°11'	256'	40°46'	309'	0.423
130° (230)	9°36'	274'	41°01'	336'	0.505
135° (225)	8°56'	293'	40°53'	365'	0.584
140° (220)	8°11'	312'	40°19'	397'	0.660
145° (215)	7°21'	329'	39°09'	430'	0.732
150° (210)	6°27'	342'	37°15'	462'	0.798
155° (205)	5°29'	346'	34°24'	488'	0.856
160° (200)	4°27'	334'	30°21'	499'	0.906
165° (195)	3°23'	299'	21°54'	476'	0.946
170° (190)	2°17'	231'	17°52'	394'	0.976
175° (185)	1°09'	127'	9°23'	231'	0.994
180° (180)	- (+) 0°00'	0'	-(+) 0°00'	0'	Aug 1.000

As is the algorithm.

Determine the Martian Longitude for a Given Date

Calculate the days between Epoch and your date				
Date			**Time Zone**	
Year	**Month**		**Day**	**Time**
2017	**3**		**18**	
Julian Day Number			**2457830**	
Difference in days				**42810**

Use the Longitude tables to find the change in Mean Longitude and Mean Epicyclic Anomaly					
Time Element (Number of Days)		**Increment (mean longitude)**		**Increment (mean epicyclic anomaly)**	
		Degrees	**Minutes**	**Degrees**	**Minutes**
100,000s					
10,000s					
1000s					
100s					
10s					
1s					
Hours					
Minutes (10 min. increments)					
Result: The total **change in mean motion** since Epoch		**0**	**0**	**0**	**0**
Add the **Mean Values at Epoch**.		**293**	**33**	**346**	**8.8**
Result: The **Mean Longitude**, and the **Mean Epicyclic Anomaly** of the planet at the		**293**	**33**	**346**	**8.8**
		Total Mean Longitude		**Total Mean Epicyclic Anomaly**	

Determine the Longitude of the Apogee

		Degrees	Minutes
Use the century year immediately before the given year, and get the result (**Use the chart**)			
Add the value for the difference between the century year and the given year, to the nearest decade			
Result: **Longitude of the Apogee**		**0**	**0**

Calculate the Mean Eccentric Anomaly

		Degrees	Minutes
From the **Mean Longitude**			
Subtract the **Longitude of the Apogee**			
Result: **Mean Eccentric Anomaly** (if < 0, add 360°)		**0**	**0**

Determine the Equation of Center

		Degrees	Minutes
Using **Mean Eccentric Anomaly** as the argument, get **Equation of Center** (q) from the table			
If **Mean Eccentric Anomaly** is between 0° and 180°, then **Equation of Center** is negative (Add - sign to both Degrees and Minutes)			
If **Mean Eccentric Anomaly** is between 180° and 360°, then **Equation of Center** is positive. Interpolate carefully			

Determine the True Epicyclic Anomaly

		Degrees	Minutes
From the **Mean Epicyclic Anomaly**			
Subtract **Equation of Center**			
Result: **True Epicyclic Anomaly**		**0**	**0**

Determine the Equation of the Epicycle

Determine the Equation of the Epicycle

Using the **True Epicyclic Anomaly** as the argument, get four quantities from the table

		Degrees	Minutes
1) **Equation at Mean Distance** (central column)			
2) **Diminution at Apogee (this is in MINUTES)**			
3) **Augmentation at Perigee (this is in MINUTES)**			
Using the **Mean Eccentric Anomaly** as the argument, get the **Interpolation Coefficient**			

Calculate Equation of the Epicycle

If **Mean Eccentric Anomaly** is less than 99° and greater than 261°, then:

		Degrees	Minutes
From **Equation at Mean Distance**			
subtract **Diminution at Apogee** * **Interpolation Coefficient**			
Result: **Equation of the Epicycle (take absolute**		0	0

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If **Mean Eccentric Anomaly** is between 99° and 261°, then:

		Degrees	Minutes
Add: **Equation at Mean Distance**			
to **Augmentation at Perigee** * **Interpolation Coefficient**			
Result: **Equation of the Epicycle (take absolute value)**		**0**	**0**

Equation of the Epicycle is *positive* if **True Epicyclic Anomaly** is between 0° and 180°

Equation of the Epicycle is negative if **True Epicyclic Anomaly** is between 180° and 360° (Add - sign to both Degrees and Minutes)

Result: **Equation of the Epicycle**			

Calculate Planetary Longitude

		Degrees	Minutes
Add: **Mean Longitude**			
to: **Equation of Center**			

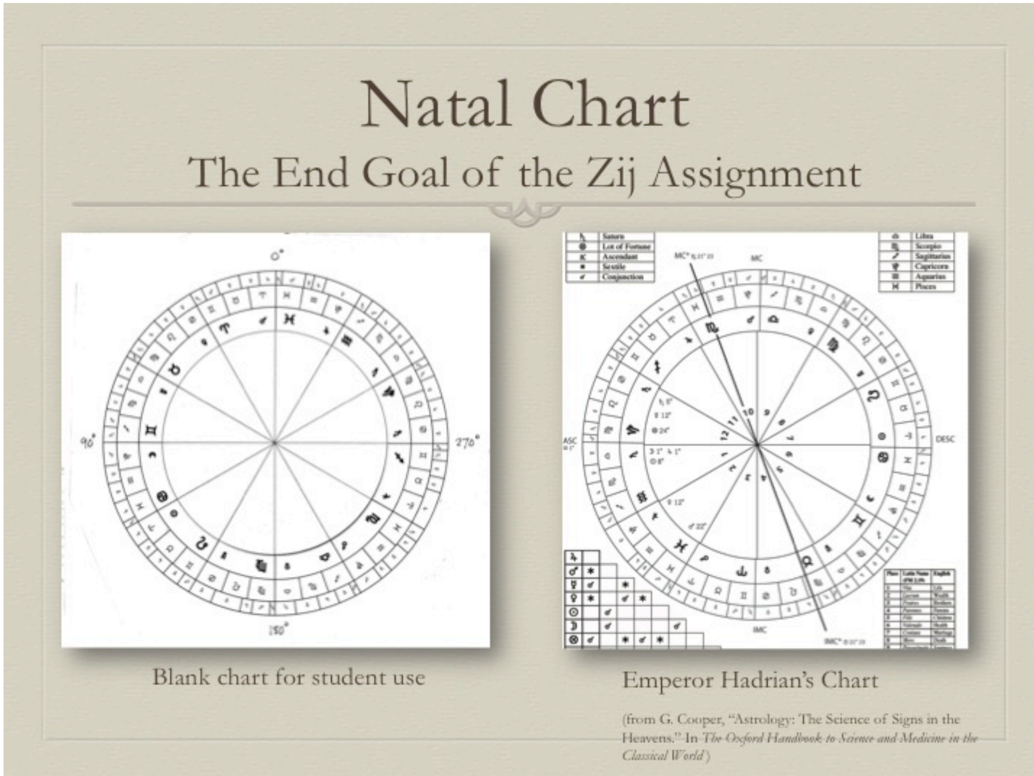
Lastly, I show them how to find the Ascendant using the Table of Ascensions for the appropriate latitude.

Table of Ascensions for London (LAT = 51° 30') and Claremont (LAT = 34° 6')

Sign	Degree	London	Claremont	Right Sphere
Aries	10°	4° 12'	6° 30'	9° 11'
	20°	8° 32'	13° 8'	18° 28'
	30°	13° 8'	20° 1'	27° 55'
Taurus	10°	18° 11'	27° 17'	37° 36'
	20°	23° 51'	35° 3'	47° 33'
	30°	30° 21'	43° 26'	57° 49'
Gemini	10°	37° 56'	52° 32'	68° 22'
	20°	46° 46'	62° 22'	79° 7'
	30°	56° 59'	72° 56'	90° 0'
Cancer	10°	68° 32'	84° 8'	100° 53'
	20°	81° 12'	95° 48'	111° 38'
	30°	94° 43'	107° 48'	122° 11'
Leo	10°	108° 44'	119° 56'	132° 27'
	20°	123° 0'	132° 6'	142° 24'
	30°	137° 19'	144° 12'	152° 5'
Virgo	10°	151° 36'	156° 12'	161° 32'
	20°	165° 49'	168° 7'	170° 49'
	30°	180° 0'	180° 0'	180° 0'
Libra	10°	194° 11'	191° 53'	189° 11'
	20°	208° 24'	203° 48'	198° 28'
	30°	222° 41'	215° 48'	207° 55'
Scorpio	10°	237° 0'	227° 54'	217° 36'
	20°	251° 16'	240° 4'	227° 33'
	30°	265° 17'	252° 12'	237° 49'
Sagittarius	10°	278° 48'	264° 12'	248° 22'
	20°	291° 28'	275° 52'	259° 7'
	30°	303° 1'	287° 4'	270° 0'
Capricorn	10°	313° 14'	297° 38'	280° 53'
	20°	322° 4'	307° 28'	291° 38'
	30°	329° 39'	316° 34'	302° 11'
Aquarius	10°	336° 9'	324° 57'	312° 27'
	20°	341° 49'	332° 43'	322° 24'
	30°	346° 52'	339° 59'	332° 5'
Pisces	10°	351° 28'	346° 52'	341° 32'
	20°	355° 48'	353° 30'	350° 49'
	30°	360° 0'	360° 0'	360° 0'

The goal of the assignment is to fill out the following chart for their own nativity. For the Moon and other planets, we must use a shortcut--I show them how to use an historical ephemeris. Eventually, I will provide future students with my own tables and

algorithms for these planets. My goal is to produce a modernized zīj that contains typical elements from the tradition, for students to study and practice with.



(Emperor Hadrian's Chart: from G. Cooper, "Astrology: The Science of Signs in the Heavens." In *The Oxford Handbook to Science and Medicine in the Classical World*. In press.)

So far the students are grasping all of this. Some have required individual attention, but once they grasp the underlying principles, most of the rest comes easily.

Abū Ja'far al-Khāzin (late 10th C.) in his *Zīj al-Ṣafāʾih* devised plates that combined zīj-like tables and equatorium-like plates to enable finding of the planets' true longitudes.[22] The culmination of the equatorium tradition in Islam was al-Kāshī's 15th C. planetary longitude computer.[23]

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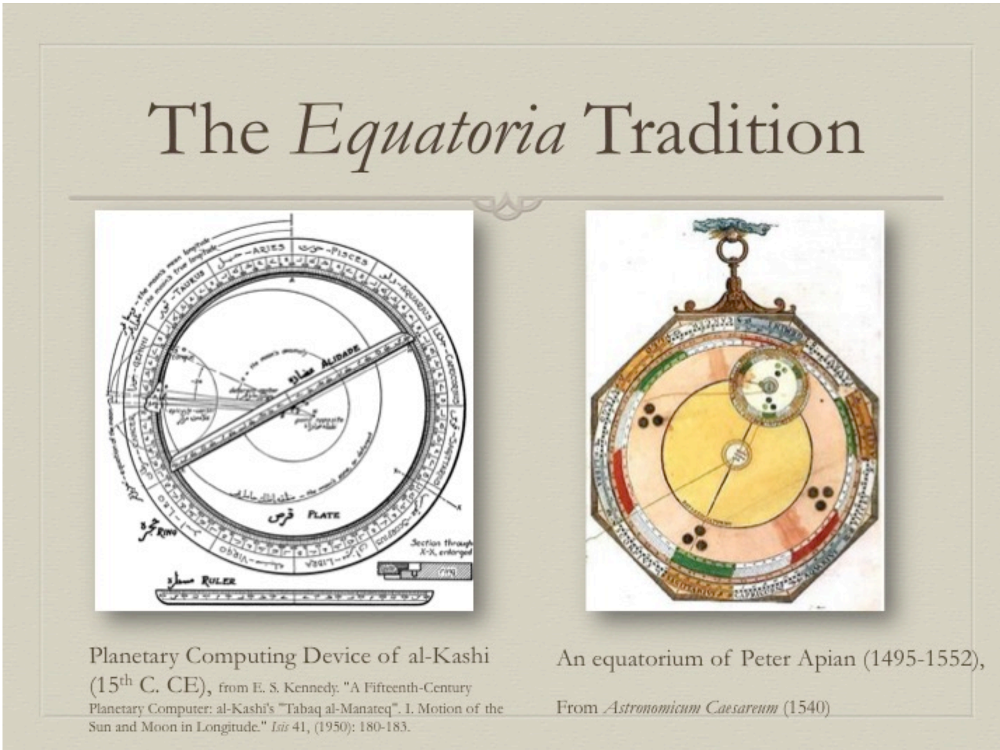
[22] Labarta, Emilia Calvo. "The Treatise on the Zij al-Safa'ih by Abu Ja'far al-Khazin. A Preliminary Study." In *Tehran 1998 Conference Proceedings: Sciences, techniques et instruments dans le monde Iranien (Xe - XIXe siècle), Actes du colloque tenu à l'Université de Téhéran (7-9 juin 1998)*, edited by N. Pourjavady and Z. Vesel, 67-78. Tehran: Presses universitaires d'Iran & Institut Français de recherche en Iran, 2004.
[23] E. S. Kennedy. "A Fifteenth-Century Planetary Computer: al-Kashi's "Tabaq al-Manateq". I. Motion of the Sun and Moon in Longitude." *Isis* 41, (1950): 180-183.

In the future, I plan to teach them how to use equatoria, or analog computers for computing planetary longitudes graphically, based on al-Kāshī’s intriguing 15th C. device, and the 16th C. cardboard models of Peter Apian.



Conclusion

I have asked students to fill out a questionnaire about these assignments, to help me improve them. I have selected passages from their comments that indicate how effective these assignments were. [Used by permission].

"What a great way to learn about Islamic culture!"

"My dad is an engineer, and I can't wait to show him how to use this astrolabe."

“[This assignment] really shows us how hard scientific discovery was since we take our ability to discover by using great technologies for granted a lot of the time.”

“My favorite part about the workshop was simply gaining an understanding the complex and intelligent systems that people during those time periods put in place to gain an understanding of time and the heavens.”

“It was unbelievable to realize how smart and observant the men who built and constructed astrolabes actually were.”

“The attention to detail and the focus that these people put on the heavens to assist in navigation, time, and astronomy was very impressive to me personally.”

“I also liked that we physically constructed the astrolabes together, not just having them given to us.”

“My favorite aspect was the astrolabe being a great hands-on way to learn. After doing so many lectures, it can be easy to not retain all the information after a while.

The astrolabe activity let me learn a lot about how science could be used for religious practices. Practically everything that the astrolabe could tell had some kind of tie to Islamic culture and tradition as a whole.”

“I liked how [the planetary tables assignment] tied into the astrolabe but also expanded on what the astrolabe taught. It showed that these simple numbers from the astrolabe coupled with certain charts could lead to unbelievable predictions that I thought were only possible in the modern day.”

“The planetary tables ... [were] big things that I thought NASA scientists were doing [that] could be done relatively easily with the correct methods.”

“I liked how we were applying what the Middle Easterners used to tell time in class so we could get a true understanding about the astrolabe.”

“Using their technology helped me put myself in their shoes better.”

“If we were only taught the function of the instrument through lecture, my understanding of its importance would not have been fully attained without actually using it.”

“It made me more aware of how complicated the science world was back then. ... I am now more aware of how important these past scientific tools are and grasped a greater appreciation for them.”

“I liked how we were able to integrate the concepts we learned in a lecture setting to an actual hand-held tool.”

“The workshop served as an effective way to apply what we learned in class in a practical way.”

“It was neat to be able to act like an ancient astronomer and use the astrolabe to perform calculations. Since most history classes are composed of discussions and

> writing, it was a nice change of pace and fun to do a hands-on activity to learn about ancient history."

> "Being able to physically conduct calculations myself gave me a more holistic understanding of astronomy and ancient technological tools. Just like lab in the science class helps practice scientific concepts, these workshops help more fully understand astronomy."

> "Such a practical exercise has never been done in any of my classes before, and so this was refreshing and meaningful."

Here's a creative suggestion for improving the assignment:

> "I think it could have been very interesting to be placed in a "situation" in which we had to use the astrolabe to solve a problem people had faced. If there was an element of creativity added to the assignment in which we had to problem solve it could really improve the assignment. This problem should be related to the issues that people had to solve with the astrolabe when it was a primary instrument used."

My own assessment is that these activities fit well within a discussion of astronomical theory in the Islamic tradition and the place of astronomy in Muslim civilization. I will use them again, but improved and expanded.